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Use of surface testing devices to identify potential risk factors for synthetic equestrian surfaces

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Abstract

Mechanical properties of sports surfaces have previously been shown to be influenced by surface drainage, moisture content and compaction but these factors have not yet been quantified for equestrian surfaces. The aim of the study was to examine the effect of three moisture levels (11.96 ± 1.63%, 17.31 ± 1.14%, 19.08 ± 0.78%) and three rates of compaction (1.647±0.02 g/cm^3, 1.748±0.046 g/cm^3, 1.766±0.039 g/cm^3) on the functional properties of a synthetic equestrian surface constructed over two distinct drainage profiles. The surfaces with a high (19.08%) moisture content and medium density when laid on permavoid™ had the most favourable results when taking into account all of the measured parameters with regards to reducing the risk of injury yet potentially offering sufficient support to the horse for efficient locomotion.

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Keywords: Equestrian surface; Hoof-surface interaction; Functional surface properties; Bulk density; Moisture Content

1. Introduction

Synthetic arena surfaces are widely used throughout the equine industry for training and competition. The surface a horse works on has been documented as a risk factor for injury amongst other variables such as conformation, type of training and discipline by Murray et al. (2010) and Peterson et al. (2012). Research has predominantly focused on racing surfaces due to the economic loss associated with the high injury rates however, more recently the effects of arena surface properties on the hoof surface interaction has become a greater interest. The intention

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of this recent work has been to identify surface characteristics that either support an optimal performance or alternatively pose a risk factor for injury.

The hoof-surface interaction has been shown to alter according to; surface type and density by Barrey et al. (1991); preparation method by Northrop et al. (2013) and Walker et al. (2012); and surface moisture content by Ratzlaff et al. (1997). Drainage and compaction caused by usage are other factors that have been reported to affect hardness and traction of sports surfaces by Brosnan et al. (2009) but this has not yet been quantified for equestrian arenas. A synthetic surface with changeable functional properties is considered to be a risk factor for injury in horses by Peterson et al. (2012), however there is limited evidence to explain the interaction between various surface features. The aim of this study therefore, was to examine the effect of changing surface moisture content, surface density and drainage system on the functional properties of an equine sand and fibre arena surface. It was hypothesised that alterations in moisture, surface density and drainage would initiate significant changes in the functional properties of the surface.

2. Materials and methods

2.1. Study Design

The effect of three different moisture contents (11.96 ± 1.63%, 17.31 ± 1.14%, 19.08 ± 0.78%) and three different compaction densities (1.647±0.02 g/cm^3, 1.748±0.046 g/cm^3, 1.766±0.039 g/cm^3) on a commercially available sand and fibre equestrian surface (93.84% sand, 5.15% fibre and 1.01% binding polymer) were studied. The surface was prepared twice in order to investigate drainage effects of i) a traditional limestone base and ii) permavoid™ units, which are high strength, interlocking plastic modules and were used under the 2012 Olympic equestrian footing. Nine unique treatments were therefore applied to each drainage effect.

2.2. Materials

In order to test the surface under the same controlled conditions, test chambers were constructed (L100cm x W98cm x D20cm) and the dimensions of which were selected according to the Boussinesq equation as stated by Das (2008) in order to reduce the boundary effect on the measured parameters. Geotextile membrane was secured to the base of the two test chambers prior to installing 238 kg of surface material to a depth of 15 cm in order to simulate an arena setting. The test chambers were placed above each of the drainage systems (Figure 1a and 1b).

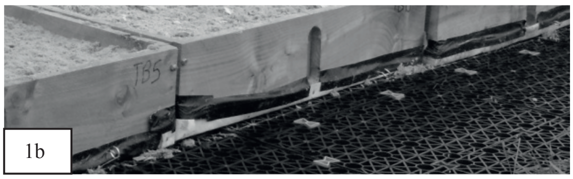

Figure 1: a) Limestone gravel drainage, b) Permavoid™ drainage.

2.3. Experimental protocol

Surface testing devices were used to quantify the response of the surfaces to the different treatments (Figure 2). The OBST has an aluminium hoof that simulates the collision from the point at which the forelimb contacts the ground at gallop to when the weight of the horse is transferred to the hoof. The initial part of the stride cycle is associated with impact shock, high loading rates and high shear loads and then high peak loads when the weight of the horse is transferred to the hoof. Consequently this part of the hoof-surface interaction is associated with high injury risks. The forces and accelerations are generated by accelerating the hoof and instrumentation equating to 33 kg down the long rails (1.015 m), which provides energy at impact of approximately 329 J. The motion of the device has been described in greater depth by Peterson et al. (2008). The OBST was dropped four times on each surface for each treatment. Simultaneous data were collected from a single axis load cell, a tri-axial accelerometer, a string potentiometer and a linear potentiometer at a sampling rate of 2000 Hz using LabVIEW software. The parameters measured included the maximum load, maximum loading rate, the maximum vertical deceleration and hysteresis, which was derived from the area under the load-displacement curve.

The Clegg Hammer, which has shown to be a good indicator of surface density according to Brosnan et al. (2009), was dropped four times in the same location using the standard protocol adopted by Clegg (1976) from a height of 0.45m. This was repeated four times for each treatment on each surface. The maximum reading of the four drops was reported due to it being considered the most repeatable measurement by ASTM (2007). A traction device was dropped once in four different locations within the test chamber for each treatment from a height of 0.2 m. A reading was taken when the equipment twisted independently from the surface. To establish the exact moisture content of all the surfaces, a sample of 100 grams (g) was taken from each test chamber after each treatment, before being dried in an oven at 102 ˚C for 24 hours and weighed again.

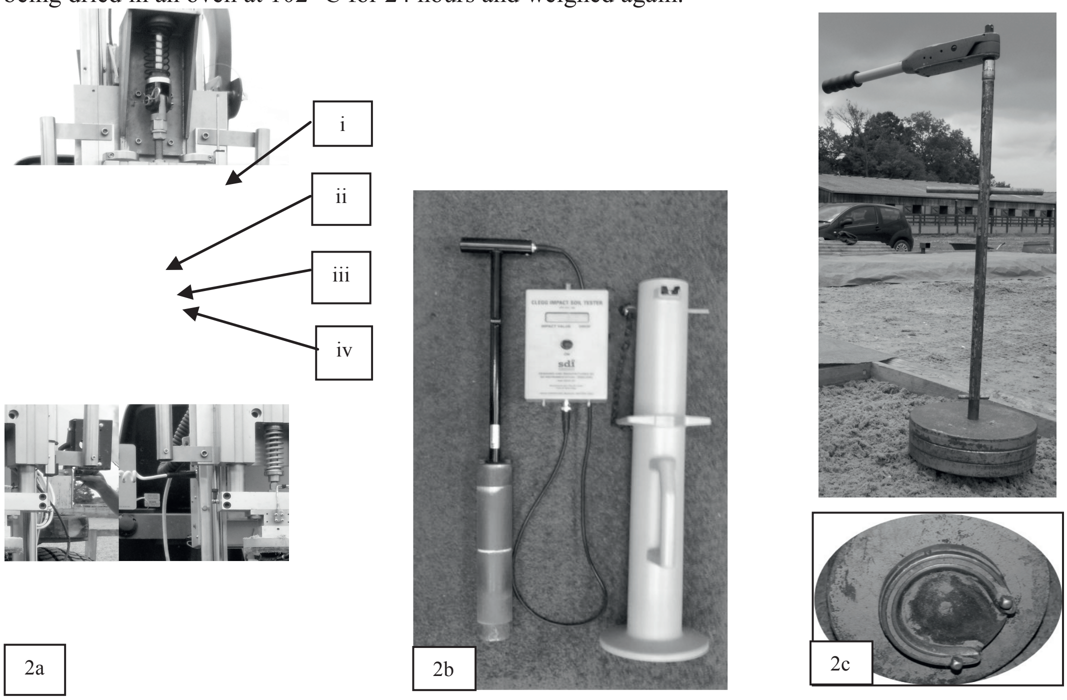

Figure 2a) The Orono Biomechanical Surface Tester: i) linear potentiometer, ii) triaxial accelerometer, iii) single axis load cell, iv) aluminum hoof; 2b) 2.25 kg Clegg Hammer; 2c) a 30 kg traction device with a horse shoe and two studs secured to the base plate.

Three test days were allocated for each level of moisture and during each day, the surfaces were prepared to three densities to replicate low, medium and high amounts of traffic. Examples of traffic would include activity from horses, humans and vehicles that would compact the top surface. The chambers were filled at 3cm increments, levelled and compacted manually with a "tamper" across the whole of the surface until a depth of 12cm was achieved and then the final 3cm layer was prepared for the appropriate surface density. To replicate a low amount of traffic, the top 3cm layer of all the surfaces were raked. To replicate a medium amount of traffic, the top 3 cm layer was struck three times with moderate force using the "tamper" in order to reduce the surface depth to approximately 14cm. To replicate a high amount of traffic, each surface was struck five times with maximum force in order to reduce the surface depth to approximately 13cm. To quantify the maximum impact force that was used to compact the surface, an accelerometer was rigidly attached to the "tamper". The suite of mechanical tests were performed on each test chamber before altering the surface density. The surface was re-constructed before altering the surface density, which involved digging up and re-levelling the top 3 cm layer of the surface. The test chambers were emptied and re-filled after each test day in order to run the tests again under a different moisture level and to avoid previous testing influencing the results.

2.4. Statistical Analysis

A One Way ANOVA was used to determine any significant treatment effects (moisture and density) and the residual values were tested for normality using a Kolmogorov-Smirnov test. Comparisons between treatments were performed using the Tukey method. A two sample t-test was used to determine the effects of drainage on the different parameters. Values of $P<0.05$ were considered statistically significant. A Kruskal Wallis (moisture and density) or Mann-Whitney U Test (drainage) were used if the data was not normal.

3. Results

The measured parameters were significantly affected by surface moisture content, density and drainage type (Table 1). Moisture had a variable effect on the parameters. Traction was lower when the surface had a low moisture content whereas hardness was generally higher. An increase in surface density increased the magnitude of all the parameters except the traction values. The permavoid™ units were responsible for reducing the magnitude of all the parameters except traction.

Table 1: Mean (S.E.) and median * values (non-normal data) of the surface parameters for the different treatments (Moisture and surface density and drainage type). Different letters $^{a-f}$ denote significant ($P<0.001$) differences within each treatment for each of the parameters unless stated otherwise. L=Low, M=Medium, H=High, Mo=Moisture, D=Density

	Surface Parameters					
Treatments	Maximum load (kN)	Load rate (kN/ms)	Max vertical deceleration (Gravities)	Hysteresis (Joules)	Hardness drop 4 (Gravities)	Traction (Nm)
Moisture and Density						
L Mo, L D	6.994 (0.16)^{bc}	0.785 (0.04)^{bc}	49.2 (2.97)^{cd}	182.19 (1.58)^{ab}	69.63 (1.7)^{c}	16.375 (0.63)^{c}
L Mo, M D	7.583 (0.34)^{ab}	1.056 (0.18)^{abc}	59.61 (3.81)^{abc}	186.15 (2.53)^{ab}	75.5 (1.88)^{bc}	17.125 (0.3)^{c}
L Mo, H D	8.274 (0.3)^{a}	0.962 (0.09)^{abc}	62.6 (2.65)^{ab}	190.02 (3.11)^{a}	84.25 (1.29)^{a}	17.25 (0.59)^{c}
M Mo, L D	6.338 (0.19)^{c}	0.704 (0.06)^{c}	51.8 (2.42)^{bc}	177.93 (2.61)^{ab}	61.0 (1.57)^{d}	22.875 (0.74)^{ab}
M Mo, M D	7.851 (0.12)^{ab}	1.29 (0.22)^{ab}	63.78 (2.72)^{a}	175.29 (4.75)^{b}	72.25 (1.31)^{bc}	20.875 (0.61)^{b}
M Mo, H D	8.586 (0.2)^{a}	1.58 (0.17)^{a}	63.52 (1.73)^{a}	185.69 (3.08)^{ab}	75.88 (2.06)^{bc}	20.375 (0.57)^{b}
H Mo, L D	6.818 (0.18)^{bc}	0.689 (0.05)^{c}	40.87 (1.69)^{d}	184.12 (2.44)^{ab}	61.13 (1.17)^{d}	25.0 (0.87)^{a}
H Mo, M D	7.529 (0.12)^{ab}	1.318 (0.21)^{ab}	55.06 (1.95)^{abc}	180.28 (1.28)^{ab}	69.75 (1.6)^{c}	22.75 (0.56)^{ab}
H Mo, HD	8.666 (0.5)^{a}	1.221 (0.14)^{ab}	57.86 (1.62)^{abc}	184.28 (4.84)^{ab}	78.0 (1.34)^{ab}	22.75 (0.65)^{ab}
Drainage		*		P = 0.049		*
Gravel	7.931 (0.2)^{a}	1.09^{a}	56.08 (1.83)	185.07 (1.9)^{a}	72.53 (1.48)	21.0
Permavoid™	7.302 (0.11)^{b}	0.81^{b}	55.94 (1.51)	180.72 (1.0)^{b}	71.33 (1.31)	21.0

4. Discussion

The present study has demonstrated that moisture, density and drainage initiate significant changes in the functional properties of the surface, some of which potentially generate a risk factor for injury in horses. Unlike sports surfaces for human athletes, it is generally believed that a surface that poses a greater risk of injury is associated with a higher level of performance whereas a surface that has shock absorbing properties increases muscular effort and will be detrimental to performance as discussed by Chateau et al. (2010) and Dura et al. (1999).

The dynamic properties of a surface should ideally have a low amount of energy lost to the surface on impact and low vertical deceleration in order to minimise the effects of the surface on the locomotor stresses of the horse as proposed by Ratzlaff *et al*. (1997). A surface that can also support greater peak loads during the support phase of the stride may be associated with a better performance, which has been found previously by Crevier Denoix et al. (2010) when measuring the effects of firm wet beach sand and deep wet beach sand on equine kinematics. A greater stride length and a lower stride frequency were recorded on firm wet sand where peak vertical loads exceeded 7 kN in comparison to deep wet sand with a mean peak vertical load of 6.1 kN when measured using a dynamometric horseshoe, which suggests better locomotion efficiency. Maximum loads recorded during this study exceeded 7 kN when the surface had a medium to high density, which may be more favorable in terms of performance. An increase in surface density also increased the magnitude of most of the other parameters with the exception of traction however. The higher loading rates, hysteresis, vertical decelerations and hardness readings when the surface had a high density would create a risk factor for injury.

Repeated exposure to high loading rates and impact shock, induced by the cyclic loading of the limbs may increase the vibrations being transmitted through the limbs as found by Barrey et al. (1991) and Radin et al. (1978) and therefore a lower surface density may be more desirable in terms of reducing the risk of injury. The findings made by Kai et al. (1999) suggest that surface density can be reduced in practice through harrowing and should be encouraged to avoid an undesirable rate of compaction. A low surface density however, may reduce locomotion efficiency as found previously by Chateau et al. (2010), where deep dry sand was associated with a greater stride frequency and shorter stride length in comparison to firm wet sand. The lower maximum loads recorded during this study when the surface had a low density, also suggests that the surface may not be able to provide sufficient support for the horse and would be undesirable in terms of supporting a good performance. A change in moisture content in conjunction with altering the surface density could create more favourable conditions according to the results of this study. A high moisture content (19.08%) was associated with higher maximum loads yet lower hysteresis and vertical deceleration values. Lower hysteresis reflects a smaller amount of energy lost to the surface on impact and may reduce the propulsive effort of the horse during locomotion according to Crevier Denoix et al. (2010). This was not always significant however there may be potential to alter the surface moisture content and density in order to reduce the risk of injury yet maintain more efficient locomotion..

Traction values increased as moisture content increased, which is considered to be related to greater particle adherence and stability of the surface by Murray et al. (2010). A surface with greater traction may be beneficial in order to provide sufficient support to the horse during activities such as jumping however, Pratt (1997) suggests that too much grip may exert larger-than-normal bending moments on the cannon bone, resulting in injury. Excessive hoof slide can similarly increase the risk of injury as discussed by Peterson et al. (2012) due to the surface not supporting the limb during the loading phase of the stride cycle and therefore the optimal traction required needs further investigation.

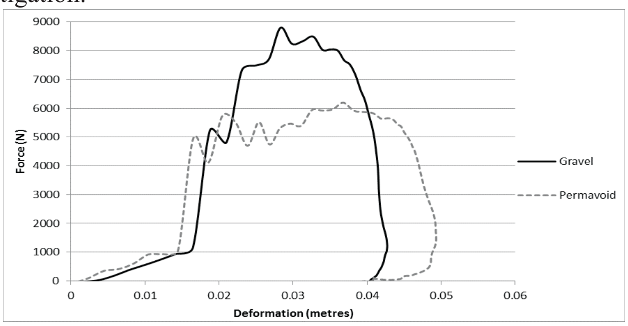

Figure 3: Load-displacement curve when the surface had a low moisture content and low surface density

Drainage type had a large effect on the functional properties of the different surfaces. The permavoid™ sub-base demonstrated shock absorbing properties and reduced the magnitude of most parameters, although this was not always significant. A lower maximum load may suggest that the surface cannot support the same magnitude of peak loads however, the smaller vertical decelerations, hardness readings and lower amount of energy lost on impact to the surface when laid upon permavoid™ suggests that the sub-base contributes to the structural damping properties of the surface as described by Barrey et al. (1991), probably due to area elastic deformation and recovery (Figure 3). Elastic recovery could be extremely beneficial at supporting an optimal performance however, if this occurs too soon during the support phase of the stride, then additional forces may have to be dissipated by the limbs of the horse according to Ratzlaff et al. (1997). The permavoid™ may be responsible for generating a more favourable hoof-surface interaction in comparison to interactions with surfaces laid on gravel and this necessitates further research on the effects of the sub-base on equine kinematics.

Conclusion

A complex combination of factors must be considered when preparing an arena to enhance performance and reduce the risk of injury. The results from the study imply that a surface with a higher moisture content (19.08%) and medium surface density would generate the most favourable hoof-surface interaction when taking into account performance and risk of injury. The permavoid™ units appear to contribute to structural damping, although this requires further investigation. Sub-base is however an important factor to consider during arena construction.

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